Passage of Adult and Juvenile Salmon Through Federal Columbia River Power System Dams

JUVENILE SALMON PASSAGE THROUGH SPILLWAYS

Causal Mechanisms Affecting Spill Survival

As pointed out in Table 1 and discussed in the spill survival section, above, many point estimates of survival through spillways made in recent years under contemporary conditions using PIT- or radio-tag methodologies are less than 0.98, a value typically used in recent model studies of survival through the hydropower system (NMFS 2000; Marmorek et al. 1998). In general, these lower survival estimates apply to Lower Monumental, Ice Harbor, Lower Granite, and The Dalles Dams, and suggest that conditions juvenile salmonids experience during spillway passage may differ among dams and within a dam spillway under various conditions. Here we summarize information developed to date on spillway passage survival at these dams.

Ruggles and Murray (1983) reviewed fish responses to passage through spillways at Canadian dams and concluded that spillways were not a serious source of fish mortality. They pointed out that fish may be injured by rapid pressure change, rapid deceleration, shear forces, turbulence, abrasion, and the force of striking water in free fall. They noted that spillway deflectors have been used successfully to reduce air entrainment associated with deep plunging jets, and that injuries begin to occur when the impact velocity of a fish striking the water surface exceeds 53 fts^{-1}. Based on a need to design spillway flow deflectors for gas abatement, the Corps initiated a literature review of physical injury through spillways through their Dissolved Gas Abatement Study. The study considered three injury types: immediate mechanical injury, short-term delayed injury, and longer-term delayed injury. It concluded that results from studies of impacts from gas abatement structures (such as flow deflectors) have been inconsistent, and effects from gas abatement structures could not be separated from effects associated with passage through the total spillway environment. Immediate direct mortality was the injury type most studied and best understood, and long-term delayed mortality was the least studied and understood. The report noted that gas abatement structures can produce hazardous conditions, such as shear zones (R2 Resources 1997).

Several years of research conducted at The Dalles Dam was summarized by Ploskey et al. (2001). A spill discharge of 40% of total project discharge was adopted as the best operation and implemented in the spring of 2000. However, testing that year showed that survival was still low in 6 of 8 conditions tested, which included 2 spillway release locations (north and south), and daytime and nighttime releases during both the spring and summer periods. Average survival ranged from 0.842 for summer, daytime, north spillway to 1.026 for spring, daytime, north spillway (Absolon et al. 2002). Subsequently, a committee of engineers and biologists used a 1:80 scale general hydraulic model at the Corps Engineering Research and Development Center in Vicksburg, MS to evaluate physical conditions associated with these elevated spillway mortality rates. They concluded that large volumes of spill through the northern half of the spillway, designed to enhance tailrace egress, resulted in flow from southern spill bays moving northward within the stilling basin. This increased retention time in the basin, along with it being half the depth of the next shallowest basin of the FCRPS dams, suggested that mechanical injury from strike and shear in the turbulent stilling basin was causing the reduced survival.

Results from more recent radiotelemetry (Beeman et al. 2002; 2003) and balloon-tag (Normandeau, 2003b) studies corroborate these observations. Therefore, an extension of the pier wall between bays 6 and 7 downstream to the stilling basin end-sill was evaluated in the Corps hydraulic model. In the model, the wall reduced retention time in the stilling basin when six, northern-most spill bays were operated under uniform discharges of from 8 to 20 kcfs. The pier wall extension was installed at The Dalles Dam prior to 2004. Preliminary results based on balloon tagging indicate direct survival was greater than 0.98, and more than 96.8% of the test fish showed no signs of injury (Mike Langeslay, Corps of Engineers, personal communication, May 2004).

At Ice Harbor Dam, spillway survival of radio-tagged yearling chinook salmon averaged 0.978 in 2000, and 0.892 in 2002 (Eppard et al. 2001, 2003). The 2000 Biological Opinion called for night spill up to 100 kcfs (the gas cap limit) and day spill of 45 kcfs during the spring at Ice Harbor Dam, with uniform spill discharge across bays. To further investigate survival associated with higher (plunging flow) and lower (skimming flow) spill volumes, BiOp and 50% spills were tested during the spring of 2003 using a 2-day block study design. Relative spillway passage survivals were similar, with 0.948 (95% CI: 0.915-0.981) for the BiOp spill and 0.928 (95% CI: 0.860-1.000) for the 50% spill. Also that year, estimated survival of balloon-tagged yearling chinook salmon released at two locations (elevations) in spill bay 5 was greater than 0.98 during all conditions tested (Heisey et al. 2003). Although fish injuries ranged as high as 22% for releases made at the deepest elevation and were 8% or less for the shallower release location (Heisey et al. 2003), these release locations appeared to represent a relatively low percentage of the overall population passing the spill bay (Moursand et al. (2003b). Efforts to resolve this issue are continuing. In 2004, preliminary results from balloon-tag studies with yearling migrants released at locations more representative of the overall population indicate survival was still high (>0.98), but injury rates were reduced to 2% (Marvin Shutters, Corps of Engineers, personal communication, May 2004).

Survival of subyearling chinook salmon at Ice Harbor Dam during the summer averaged 0.885 in 2000 and 0.894 in 2002 (Eppard et al. 2001, 2003). In 2003, a bulk-spill pattern was developed where more than 10 kcfs was spilled through fewer bays, as compared to the pattern of uniform spill through all bays. Estimated survival of PIT-tagged subyearling chinook salmon was 0.96 (95% CI: 0.90-1.10) (Absolon et al. 2003). When compared to 2000 and 2002, these results suggest the bulk-spill pattern may reduce fish exposures to physical conditions that cause injuries. In contrast, 1-hour estimated survival under the bulk spill pattern based on balloon-tagged, river-run subyearling chinook salmon, was 0.89 and 0.92 for shallow and deep spill bay release locations, compared to an estimated 1-hour survival of 0.98 for fish released through a deep release under the uniform spill pattern (Heisey et al. 2003). However, the authors indicated there were problems related to high temperatures during this test, suggesting a need for caution when interpreting these data.

At Lower Monumental Dam, Muir et al. (2001a) found that survival of PIT-tagged yearling migrants was lower though spill bays with deflectors, compared to standard bays. The study did not address differences between spill bay locations, discharges, or tailwater elevations. Prior to 2003, additional deflectors were installed in the end-bays of the spillway, and with these in place, from 25 to 40 kcfs could be spilled while maintaining gas criteria at downstream locations under 24-hour spill. In 2003, Hockersmith et al. (2003) evaluated spillway survival based on radio-tagged yearling chinook salmon where spill was distributed uniformly between spill bays. Relative survival through the spillway was 0.900 (95% CI: 0.843-0.961). Relative survival through spill bays 4 and 7 was similar, at 0.896 (95% CI: 0.779-1.031) and 0.895 (95% CI, 0.724-1.106), respectively. However, spill discharge early in the season was in the gas cap range noted above when total river discharge was less than 75 kcfs, but was outside this range later in the season when total river discharge increased. Additional analysis of the data suggested there was a tailwater elevation effect, where survival was low when tailwater elevation was low (0.834 (95% CI: 0.78-0.90), 440 ft msl, 76 kcfs river flow), and high when tailwater elevation was high (0.987 (95% CI: 0.92-1.06), 444 ft msl, 150 kcfs river flow) (Eric Hockersmith, NOAA Fisheries, personal communication, January 2004).

In summary, fish survival through spillways at these dams is influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spill bay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and thus total river flow, gate opening, and fish location when passing through the spill bay and under the control gate. Efforts to further explore the relationships between these factors are ongoing. Hydraulic model studies indicate that deflector submergence (tailwater elevation) directly influences the hydraulic behavior of the spill jet as it passes over the deflector. Under conditions of high discharge and low submergence of the deflector, the jet passes over the deflector and plunges abruptly into the stilling basin. This operation was tested during the summer of 2003 at Ice Harbor Dam and resulted in an estimated average survival of 0.96. Under conditions of moderate discharge and higher deflector submergence, the spill bay discharge jet is deflected upward, creating an undular, ramped, or submerged hydraulic jump. This operation was tested during the spring of 2003 and resulted in an estimated average survival of 0.99 at Lower Monumental Dam. Under both conditions, the spillway discharge jet appears to dissipate relatively quickly and produces low impacts on juvenile salmonids passing through the discharge, even though jet velocities are high (>60 fts^{-1}). Conversely, under conditions of low discharge per spill bay, certain tailwater elevations, and uniform spill between bays, the discharge jet performs as designed and skims off the deflector and stays near the tailrace water surface for an extended distance downstream. This operation was tested during the spring of 2002 and resulted in an estimated average survival of 0.89 at Ice Harbor Dam, and 0.83 during the spring of 2003 at Lower Monumental Dam.

Based on this information, a possible explanation of the low survival associated with skimming flow off the deflector is that a shear zone is created on the underside of the jet and fish in the lower portion of the nappe are exposed to this zone which results in injuries. The zone of injury occurs until a point downstream where jet velocity drops to below 50 fts^{-1}, a threshold considered safe based on field and laboratory studies (Ruggles and Murray 1983, Pacific Northwest National Laboratory et al. 2001). If this explanation is the case, lowering the elevation of the deflector to produce hydraulic jump conditions a greater percentage of the time, or changing to higher discharges through fewer spill bays ("bulk" spill) may reduce injury and mortality rates. Clearly, additional field and hydraulic model studies will be needed to verify this explanation, understand the implications for gas abatement, and design solutions to these conditions.

The observations of spillway survival at The Dalles, Ice Harbor, and Lower Monumental Dams suggest that survival of juvenile salmonids through spillways is influenced by many physical factors. Lessons learned from these studies should be applied to others spillways that have deflectors, and training spill associated with the Removable Spillway Weir at Lower Granite Dam and others weirs that may be installed in the future.

Add the following to the spill section conclusions:

1. Fish survival through spillways with deflectors or shallow stilling basins can be negatively influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spill bay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and thus total river flow, gate opening, and fish location when passing through the spill bay and under the control gate. Survival through spillways with deflectors or shallow basins can be considerably less than 0.98, a value typically used in hydropower system modeling exercises. Observations and lessons learned from spillway survival studies at The Dalles, Ice Harbor, and Lower Monumental Dams should be applied to other spillways with deflectors, to ensure that adequate spillway passage conditions are provided at these locations as well. Examples include Little Goose Dam where survival may be lower than previously measured under some conditions, and possibly training spill associated with the Removable Spillway Weir at Lower Granite Dam and others weirs that may be installed in the future.

<u>References to add to the Dam Passage Tech Memo Reference List:</u>

Beeman, J.W., Juhnke, S., Daniel, K., Daniel, A., Janer, P. 2003. Estimates of the stilling basin residence time and lateral distribution of passage of juvenile Chinook salmon passing through the spillway of The Dalles Dam, 2001. Prepared for U.S. Army Corps of Engineers, Portland District, Contract No. W66QKZ10805878. 37p.

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Ruggles, C. P. and D. G. Murray. 1983. A review of fish response to spillways. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1172. 31 p.